

URBANIZATION IN SUB-SAHARAN AFRICA AND IMPLICATION FOR MALARIA CONTROL

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Abstract. Malaria not only remains a leading cause of morbidity and mortality, but it also impedes socioeconomic development, particularly in sub-Saharan Africa. Rapid and unprecedented urbanization, going hand-in-hand with often declining economies, might have profound implications for the epidemiology and control of malaria, as the relative disease burden increases among urban dwellers. Reviewing the literature and using a modeling approach, we find that entomologic inoculation rates in cities range from 0 to 54 per year, depending on the degree of urbanization, the spatial location within a city, and overall living conditions. Using the latest United Nations figures on urbanization prospects, nighttime light remotely sensed images, and the “Mapping Malaria Risk in Africa” results on climate suitability for stable malaria transmission, we estimate that 200 million people (24.6% of the total African population) currently live in urban settings where they are at risk of contracting the disease. Importantly, the estimated total surface area covered by these urban settings is only approximately 1.1–1.6% of the total African surface. Considering different plausible scenarios, we estimate an annual incidence of 24.8–103.2 million cases of clinical malaria attacks among urban dwellers in Africa. These figures translate to 6–28% of the estimated global annual disease incidence. Against this background, basic health care delivery systems providing early diagnosis and early treatment and preventive actions through mother and child health programs and the promotion of insecticide-treated bed nets for the rapidly growing numbers of the urban poor must be improved alongside well-tailored and integrated malaria control strategies. We propose environmental management and larviciding within well-specified productive sites as a main feature for such an integrated control approach. Mitigation of the current burden of malaria in urban African settings, in turn, is a necessity for stimulating environmentally and socially sustainable development.

INTRODUCTION

Malaria is responsible for an estimated 300–500 million clinical attacks globally, and >1 million deaths each year mainly among children less than five years of age living in sub-Saharan Africa. The disease accounts for an estimated loss of 44.7 million disability adjusted life years (DALYs), more than 80% of which are currently concentrated in sub-Saharan Africa.¹ In the absence of effective intervention strategies and the rapid spread of drug resistance, the number of malaria cases might double over the next 20 years.² Acute febrile illness, chronic debilitation, complication of pregnancy, and impairment of the physical development and learning ability of children are typical consequences of malaria, and represent a huge negative social impact in the high burden areas.³ Furthermore, the macroeconomic toll is severe, particularly in sub-Saharan Africa, since malaria may cost more than one percentage point of economic growth every year.⁴

The demographic changes that we experience today are profound. Rapid urbanization alters the frequency and transmission dynamics of malaria, with significant effects on disease-associated morbidity and mortality, which in turn has important implications for control.^{5,6} At present, the least developed countries experience the highest urbanization rates, often in the range of 2–6% per year.⁷ Until recently, urban development was generally believed to reduce the risk of vector breeding, and thus malaria transmission. However, many African countries have declining economies, and most cities are struggling to cope with the pace and the extent of urbanization. Poor housing and lack of sanitation and drainage of surface water can increase vector breeding and human vector contact, and thus pose unique challenges for control.^{8,9} Furthermore, the adaptation of malaria vectors to urban areas has been well documented for at least two decades,¹⁰ and local transmission has been conclusively demonstrated in

many African cities.⁶ An additional problem on the human side is that a high proportion of the urban population may be at risk of severe disease due to delayed acquisition or lack of protective immunity.

Quantitative assessment of the malaria burden in urban areas together with information on socially and environmentally sound and cost-effective intervention strategies are urgently required. These data will provide a rational basis for the design, implementation, and monitoring of malaria control programs.¹¹ Especially in urban environments a high degree of heterogeneity is observed: urban dwellings typically offer a relatively narrow spectrum of focal breeding sites. These sites are often straightforward to identify and to access, providing opportunities to spatially targeting interventions.¹² A great impact on urban malaria could be achieved by eliminating key risk sites. Consequently, techniques of environmental management, particularly surface water management, within the frame of an integrated control approach, offer potentially sustainable methods to substantially reduce transmission.

The purpose of this paper is to assess and quantify the current burden that malaria imposes on urban Africa and to propose mitigation strategies. In the first section, we review urban development in Africa over the past 50 years and highlight key predictions for the next 30 years. We then develop methodologies for estimating the surface area and the number of people living in African cities that are at risk of malaria transmission, employing the latest United Nations (UN) figures on urbanization prospects, results from the “Mapping Malaria Risk in Africa” (MARA) network on climate suitability for stable malaria transmission, and nighttime lights satellite images. We provide a systematic review of the published literature on malaria prevalence and entomological inoculation rate (EIR), including new estimates of EIR in urban African settings. We describe the key malaria vectors and

their habitats. In an attempt to estimate the total number of annual malaria cases in urban Africa, we examine the relationship between EIR and annual malaria incidence. We link these data with the number of people living in varying urban environments and characterized by distinct EIR. The last section discusses issues in strengthening current control programs, by using an integrated approach consisting of early diagnosis and prompt treatment and the distribution of insecticide-treated bed nets (ITNs) as the backbone, coupled with environmental management, as a key feature to mitigate the current burden of malaria in urban African settings.

URBANIZATION IN AFRICA

The classification of urban environments is by no means uniform. Urban communities may be defined by physical borders, population size, geographic limits associated with administrative responsibilities, or governance.¹³ In Botswana, for example, urban areas are defined as agglomerations of 5,000 or more inhabitants, with the majority depending on non-agricultural activities. In Ethiopia, however, localities of 2,000 or more people are classified as urban, and in Malawi all townships, town planning areas, and all district centers are defined as urban.¹⁴ Usually inhabitants at the urban fringe are not included in the urban statistics because they are not part of a legally proclaimed area, although these areas often experience the highest population growth rates.

In Africa, many cities were developed as colonial administrative or trading centers rather than industrial and commercial zones equipped to support large populations. Urban authorities have often been unable to keep up with the rapid growth of squatter communities and shantytowns. Furthermore, stagnating and declining economies have often led to a decrease in the quality of the urban environment and deterioration in both the quality and distribution of basic services, including housing and medical facilities. As a result, urban environments exhibit significant spatial variation in their development level. Well-developed city centers are often surrounded by underdeveloped and inadequately serviced settlements supporting a large fraction of the population.

To date, the African continent is considerably less urbanized when compared with the rest of the world. For example, in the year 2001 urban dwellers in East Africa accounted for only 25% of the population (Table 1), compared with 70% and above elsewhere in the world. Current estimates by the UN predict that half of the African population will live in urban settings by the year 2025, and that the percentage will

further increase to 52.9% or 787 million in 2030.⁷ In contrast, the rural population will experience a slower growth: from 498 million in 2000 (52.8%) to an expected 702 million in 2030 (47.1%). There are two underlying reasons. First, there are strong rural-urban economically driven migrations with people seeking education and job opportunities outside subsistence farming. Second, rural settlements have evolved into small or medium size cities. In 1950, there was not one single megacity (defined as places with $\geq 750,000$ inhabitants) on the African continent. Fifty years later there were 43 megacities, already harboring 11.9% of the African population. It is estimated that in 2010 more than 100 cities on the African continent will have a population of at least 500,000, and more than half of them will be inhabited by more than one million people.⁷

MATERIALS AND METHODS

Urban population estimates in malaria endemic areas. We calculated the total number of urban dwellers living in African countries that are endemic for malaria, using the MARA map on the predicted suitability of malaria transmission in Africa, and the most recent UN data on urban populations.⁷ Based on population density maps we have included Chad, Kenya a Mali, and Niger in our estimate because their major urban centers, namely N'Djamena, Nairobi, Bamako, and Niamey, are located in areas where malaria transmission occurs. We have added the urban population of Sudan because new evidence suggests that focal malaria transmission has become established in Khartoum.¹⁵ Approximately 74% of the population is at risk of acquiring the disease.¹⁶ We have also included the urban populations of Eritrea and Ethiopia because recent research has shown that malaria has become a major public health problem with 92% and 40% of their population, respectively, at risk.^{16,17}

Surface estimates of malaria-endemic urban Africa. In the absence of precise data on surface areas of urban Africa, we used information on clusters of nighttime stable lights classified as human settlements as a proxy for urbanization. The data was collected by the U.S. Air Force Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS) during a six-month period between October 1994 and March 1995. The data are publicly available on the website <http://dmsp.ngdc.noaa.gov/html/download.html>. The OLS has a unique low-light imaging capability, which detects and distinguishes lights from human settlements, wildfires, gas flares, or fishing boats.

On average, only 41.5% of the urban housing units in malaria-endemic Africa have electricity, ranging from as low as 39% in Côte d'Ivoire and Ghana, to a maximum of 92% in Rwanda (http://www.afdb.org/knowledge/statistics/statistics_indicators_gender/poverty/pdf/tab2_9.pdf). There are further variations in the connection to the power grid between and within cities. For example, in Tanzania, the percentage of households reporting connection to the power grid in urban areas ranges from 19% to 45%. In addition, the average African electricity use per capita was estimated to be only 620 kilowatt-hours (kWh) in 1997, which corresponds to only 30.2% of the world electricity use per capita and only 7.7% of the high income countries' electricity use per capita

TABLE 1

African population in urban and rural areas and percentage urban (2001)*

Major region	Total population (thousands) in 2001	Rural population (thousands) in 2001	Urban population (thousands) in 2001	Percentage urban
Eastern Africa	256,673	192,218	64,455	25.1
Western Africa	230,259	138,208	92,051	40.0
Northern Africa	177,390	89,908	87,482	49.3
Middle Africa	98,151	62,826	35,325	36.0
Southern Africa	50,129	22,699	27,430	54.7
Africa	812,602	505,859	306,743	37.7

* Source: United Nations, 2002.⁷

(e.g., the electricity use per capita for the United States in 1997 was 11,700 kWh).^{18–20} Therefore, without any correction factor, the use of nighttime light data as a proxy for African urbanization would considerably underestimate surface areas.

On the basis of statistics on the distribution and consumption of energy in Africa as discussed earlier, we propose to multiply the surface estimates by factors equal to two and three to obtain more reasonable figures for a lower and an upper bond, respectively.

Entomologic inoculation rates, malaria prevalence, and vectors in urban Africa. We generated a comprehensive database on malaria transmission in urban and peri-urban African settings, as expressed by EIR and malaria prevalence. The EIR is defined as the number of infective bites per person per time unit. Two previous papers have compiled EIRs for urban and rural settings in sub-Saharan Africa.^{6,21} We updated and extended these compilations by performing a computer-aided systematic search of published work on urban malaria in Africa on MEDLINE® (U.S. National Library of Medicine, Bethesda, MD) and consulting with representatives from the MARA network on malaria prevalence data across Africa. Although studies of malaria transmission in urban areas date back more than 100 years, we have focused on the last 25 years because older studies might not be representative for the current situation. We only included data from urban areas that have a population of 10,000 inhabitants or more.

In many instances, we estimated EIRs from age-specific malaria prevalence data using the mathematical model of the Garki project.²² This method has been recently described by Hagmann and others.²³ Briefly, the Garki model is a dynamic model for *Plasmodium falciparum* transmission and infection that was originally fitted to data from Garki district in northern Nigeria and collected as part of a major trial of indoor residual spraying and mass chemoprophylaxis.²⁴ The mathematical model²² treats the human population as made up of individuals in each of seven distinct compartments defined by infection and immunologic status and consists of an algorithm for predicting the proportion of the human population at each age in each of these compartments, as a function of the vectorial capacity C . It is defined by a set of difference equations that specify the change in each of these proportions from one time point to the next. Within this model, the EIR is approximated by the product $C \cdot y_i$, where y_i is the proportion of the human population that is infective. To estimate the EIR from community parasitologic survey data, the equilibrium age-prevalence curves for the Garki model were estimated for different values of C , using a golden section search routine to locate the maximum likelihood estimate.²⁵ Asymptotic 95% confidence estimates were obtained by numerical estimation of the Fisher information. This procedure gives minimum estimates of the EIR because the model was developed on the assumption that none of the infections are treated. Infections that are treated soon after becoming patent do not contribute to the pool of prevalence in the community; thus they are additional to those that contribute to the EIR estimate and the true EIR is higher by a rate equal to the incidence of the treated infections. We also implemented the simple version of the model that assumes a constant vectorial capacity throughout the year. This also leads to lower estimates of the EIR than would be obtained if seasonal transmission was assumed.

We also reviewed the literature with regard to the main malaria vectors and summarize their habitat preferences, particularly for the larval stages.

Annual malaria cases in urban Africa. For the estimation of urban African malaria cases, we compiled data from the literature reporting both EIRs and annual malaria incidence rates in children less than seven years old (calculated from parasitologic survey data, and ideally including the proportion of cases observed in health facilities) in urban or rural settings in Africa. In two studies, EIRs were determined previously and published elsewhere.²¹ Only surveys conducted over a period of at least nine months, and which classified malaria as a febrile episode (usually defined as an axillary temperature $\geq 37.5^\circ\text{C}$) and detectable parasitemia were considered. We examined the relationship between EIR and annual malaria incidence by plotting data from each site on linear (incidence) and logarithmic (EIR) axes, and by performing a linear regression analysis.

RESULTS

Population at risk and surface of malaria transmission in urban Africa. Figure 1 depicts the malaria-endemic area of Africa, using nighttime lights as a proxy for urban areas and megacities. Table 2 presents selected key figures for the population and surface area of Africa in general, and more specifically for its urbanized areas at risk of malaria transmission. Our surface estimates based on data of nighttime lights images, corrected by factors of 2–3 show that urban areas in Africa represent 1.7–2.6% of the total continent's surface. The estimated urban surface in Africa at risk of malaria transmission is 330,500–492,800 km², accounting for 1.1–1.6% of the total surface area of Africa. At present, 96.8 million Africans live in 43 megacities, 28 of which are located in areas of malaria transmission. The total surface area of these 28 megacities calculated on the basis of their administrative boundaries covers only 0.08% of the total continent's surface.

We estimate that 200 million people currently live at risk of contracting the disease in urban Africa (24.6% of the total African population).

Malaria prevalences, EIRs, and malaria vectors in urban Africa. Table 3 presents a comprehensive summary of all studies pertaining to urban and peri-urban malaria in Africa that met our inclusion criteria. We further present the calculated EIR values (marked with *). We find that urban areas are characterized by low malaria transmission. The EIR estimates in city centers approach zero, indicative of very low malaria transmission. In contrast, EIRs as high as 54 have been found in peri-urban areas, depending upon rainfall patterns, temperature, geographic location, and dominant land- and water-use patterns. In close proximity to rice paddies in Bouaké, Côte d'Ivoire, characterized by marshland and many streams, an annual EIR of 126 was determined.²⁶ Dispersion of anophelines, was demonstrated to be low, with the large majority of adult *Anopheles gambiae* collected within 200–300 meters from their main breeding sites.^{27,28} A recent, longitudinal study in Kampala, Uganda has found a highly heterogeneous malaria risk with proximity to breeding places as the strongest predictor of clinical malaria.²⁹

Malaria prevalence rates also show large variation. They

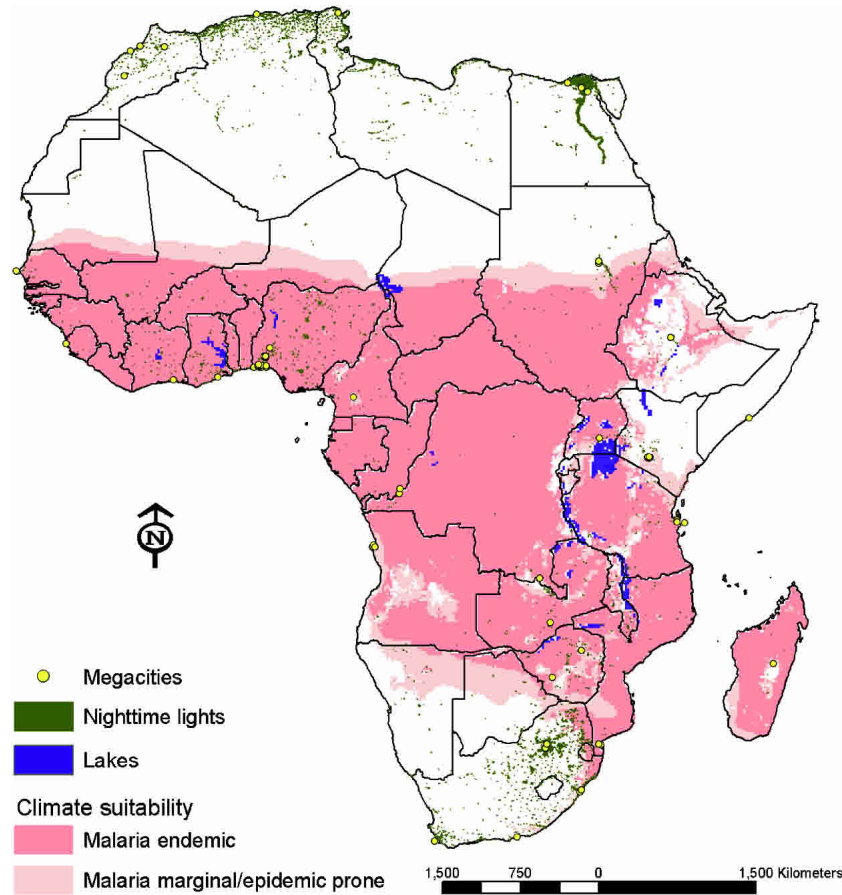


FIGURE 1. African megacities, nighttime lights, and malaria-endemic areas

may range from as low as 1% in city centers to more than 90% in suburbs. A high malaria prevalence of up to 50% within all age groups was recorded in peri-urban areas of Niamey, Niger during the rainy season³⁰ compared with only 5% in the dry season. A study in Yaoundé, Cameroon re-

ported a high malaria prevalence, which could be explained by urban aquaculture practice and house locations proximal to wetlands.³¹ Any increase in transmission due to ecologic transformation or climatic changes could therefore contribute to malaria epidemics. As might be expected, comparative appraisal of malaria prevalence rates in rural and urban settings showed significantly higher rates in rural environments; up to four-fold higher in some areas.^{28,32}

Table 4 summarizes the key features of the five main *Anopheles* species capable of transmitting malaria in urban Africa, with particular emphasis on their larval habitat preferences. Viable environmental control measures against urban vector breeding sites are also summarized in Table 4. Prominent among them are land filling or drainage work, flooding, or vegetation management.

Malaria incidence in urban Africa. *Linear relationship between malaria incidence and EIR.* We identified eight studies (three urban and five rural data points) that met all our inclusion criteria. We assume that the relationship between EIRs and incidence rates obtained from these data can be applied to all age groups in urban settings. This might be justified because all age groups are similarly susceptible to the disease, which is in sharp contrast to rural settings where children less than five years of age and pregnant women are at highest risk of disease-attributable morbidity and mortality.³³ The obtained data supported a linear relationship between malaria incidence and the logarithm of annual EIR

TABLE 2

Population and surface of Africa according to classifications of megacities, urban areas, and malaria-endemic transmission areas (2001)

Geographic unit	Population (millions)	Area (thousands of km ²)
Africa	812.6*	30,313
Malaria-endemic area	601.7 (741.0%)†	15,156 (50.0%)‡
Urban Africa	306.7 (37.7%)*	518.3–776.0 (1.7%–2.6%)§
Urban malaria-endemic area	200.0 (24.6%)¶	330.5–492.8 (1.1%–1.6%)§
Megacities#	96.8 (11.9%)*	60.6 (0.18%)**
Megacities malaria-endemic area	60.5 (7.4%)††	25.01 (0.08%)**

* Based on the UN World Urbanization Prospects, 2001.⁷

† Based on calculations given by Snow and others³⁴ and the growth rate from UN World Urbanization Prospects, 2001.

‡ The total area of endemic places was computed from MARA maps available at <http://www.mara.org.za>.

§ Area estimated by nighttime satellite images (see Materials and Methods for further details).

¶ Comparing population density maps and malaria transmission maps (urban inhabitants excluding South Africa, Botswana, Namibia, northern Africa, Somalia, and Djibouti), as described in the Materials and Methods.

Defined as areas with 750,000 or more inhabitants.

** Area estimated from administrative boundaries from megacities.

†† All megacities excluding those located in northern Africa and South Africa.

TABLE 3
Malaria prevalence and entomologic inoculation rates (EIRs) in African cities

Study setting, period (reference)	Sample size	Malaria prevalence		EIR	
		Urban (%)	Peri-urban (%)	Urban (%)	Peri-urban
Benin					
Cotonou 1989 ⁵²	152 children	19.1		1.2* (Camp Guezo)	
Cotonou 1989–1990, 2000 ⁵³	3,582 children	51.7–63.8 (seasonal variations)	70.1–91.7 (seasonal variations)	29	47
Burkina Faso					
Ouagadougou, 1984 ²⁸	2,117 children	3–26 (6 sites)		1.2*	
Ouagadougou, 1984 ⁵⁴				0	23
Ouagadougou ⁵⁵				0.3	12
Ouagadougou, 1993 ⁵⁶	290 individuals (all age groups) 4,128 medical observations			4	
Bobo-Dioulasso 1985 ^{57,58}				0.1	4.6
Cameroon					
Ebolowa, 1993–1995 ⁵⁹	206 children	30.9		1.2*	3.8 (well planned suburb); 30 (densely populated suburb)
Edea, 1990 ⁶⁰					
Limbe, 1987 ⁶¹	407 children	33.1		1.8*	
Yaoundé, 1986 ⁶²	336 children	9.2		1*	
Yaoundé 1989–1990 ³¹	960 individuals (all age groups)	10 (February)–42 (May)		1.9*	
				3;13 (authors' estimates)	
Yaoundé 1989–1990 ⁶³					14–30
Yaoundé 1996–1997 ⁶⁴	576 children		52		3*
Congo					
Talangaï, Brazzaville 1980 ⁶⁵	125 children		22.4		1.3*
Brazzaville 1980–1982 ⁶⁶	555 schoolchildren (5–14 years old)	9–80 (5 sites with different degree of urbanization)		1–7.7	
Brazzaville 1982–1984 ⁶⁶				0.3–101	
Lubumbashi, 1997 ⁶⁷	625 children	60.9		4.9	
Côte d'Ivoire					
Bouaké City 1992 ⁶⁸				88 (market garden districts), 126 (rice field districts)	
Democratic Republic of the Congo					
Kinshasa 1980 ⁶⁹	2,267 children	33		3.6	
Kinshasa 1985 ⁷⁰	420 children	37		2.3*	
Kinshasa 1988–1989 ³⁵				29 (poorly developed sector)	
Kinshasa 1989–1990 ⁷¹				2.9	
Ethiopia					
Nazareth 1988–1989 ⁷²	3,890 individuals in 4 surveys (all age groups)	1.1	4	0.9*	
Gabon					
Franceville 1994 ⁷³	109 children	43.9			
Franceville 1993–1995 ⁷⁴					81
Libreville ⁶⁴	507 children		65		6.4*
The Gambia					
Bakau 1988–1989 ⁷⁵	500 children		2		0.28
Bakau 1990 ⁷⁶	29 adults	17.2		1.3*	
Ghana					
Accra 1978 ⁷⁷	413 individuals (all age groups)	1.4		0.9*	
Nima, 1988–1990 ⁷⁸	506 children (6–15 years old)	18		1.3*	
Sunyani, 1988–1990 ⁷⁸	715 children (6–15 years old)	21.3		1.2*	
Ho, 1988–1990 ⁷⁸	451 children (6–15 years old)	29.9		1.6*	
Bolgatanga, 1988–1990 ⁷⁸	706 children (6–15 years old)	39.7		2.1*	
Guinea					
Labe 1989 ⁷⁹	310 individuals (all age groups)	16.7			

TABLE 3
Continued

Study setting, period (reference)	Sample size	Malaria prevalence		EIR	
		Urban (%)	Peri-urban (%)	Urban (%)	Peri-urban
Guinea-Bissau					
Bandim 1994 ⁸⁰	312 children	59		3.4*	
Kenya					
Kilifi town 1990–1991 ⁴⁸	81 children	17.1		1.5	
Madagascar					
Antananarivo, 1995–1996 ⁹¹	1,545 children 932 patients	0.8 (school group) 2.6 (patients)			
Mozambique					
Matola, 1994–1996 ⁸¹	6,000 individuals (all age groups)	33 (dry season) 63 (rainy season)		27	
Matola, 1994–1995 ⁸²	3,199 individuals	5.4–59 (several sites)			0–20
Niger					
Maradi 1985 ⁸³	182 individuals (all age groups)	1.6		0.9*	
Niamey 1992–1995 ³⁰	Not known	0–5	5–50		
Nigeria					
Ibadan, 1989–1991 ⁸⁴	1,345 children	22.6 (dry season) 38.1 (rainy season)		6*	
Ibadan City 1994 ⁸⁵	343 students (14–19 years old)	8			
Senegal					
Pikine 1979–1981 ⁴⁵	296 children in 7 surveys	8.8		14	
Dakar (Pikine ancien) 1987–1988 ⁸⁶	2,465 individuals (all age groups)	3.8		0.12 0.9*	
Dakar 1994–1997 ^{51,87}	4,925 individuals (all age groups)	1		0	
Sudan					
Khartoum 1995 ¹⁵	4,614 samples (all age groups)		3.7–5.5 (2 sites)		0.9*
United Republic of Tanzania					
Dar es Salaam 1988–1996 ⁸⁸	6 primary schools	2.8 (February) 73 (September)			
Ifakara 1999 ⁸⁹				15	54
Togo					
Sokode 1986 ⁹⁰	707 children	37.2		1.9*	
Zambia					
Lusaka 1984–1985 ³²	423 children	2.4 (November) 10.3 (April)			

* Estimated EIR (see Materials and Methods for further details).

with $r^2 = 0.74$ (Figure 2). The linear regression analysis fitted to malaria incidence data obtained from community surveys and EIR obtained in the same settings resulted in the following equation: Annual malaria incidence (per 1,000) = $408 \log_{10}(\text{annual EIR}) + 153$.

Malaria incidence in different urban environments. The urban poor are found to face similar health risks when compared with the general rural population. Poor people are at increased risk both of becoming infected with malaria and of becoming infected more often.¹⁶ According to recent evidence, households characterized by extreme poverty and unsatisfactory basic services account for more than 40% in African cities (http://www.johannesburgsummit.org/html/media_info/pressreleases_factsheets/wssd10_africa.pdf). Therefore, we split the total urban African population in malaria endemic areas (our estimate of 200 million) into 80 million poor (40%) and 120 million (60%), living in more satisfactory conditions. We divide the poor urban Africans into two sub-groups according to their geographic origin. Approximately 10.5% of these (8.4 million) live in unstable,

fringe, or epidemic malaria transmission areas,³⁴ which are exposed to very low EIRs of approximately 0–1. The remaining 89.5% (35.8 million) urban poor live in high malaria transmission zones where, as we have summarized in Table 3, EIRs range between 3 and 30 (e.g., Kinshasa³⁵). Those 120 million of urban Africans living in areas with adequate conditions, thus at low malaria risk, are exposed to few infective bites per year (Table 3), resulting in EIRs of 0–4.

With assistance of the estimated linear relationship and the assigned EIR to the African population living in three distinctively different urban environments we estimate that 24.8–103.2 million malaria cases occur annually in urban Africa. First, in the poor environments in low transmission areas, 0–1.3 million cases of malaria are likely to occur annually. Second, 0–47.8 million malaria cases are expected to occur among the 120 million residents of standard urban housing areas in high transmission areas. Third, the largest number of annual cases, namely 24.8–54.1 million, occurs in environments characterized by high malaria transmission and poverty (Figure 3).

TABLE 4
Major African malaria vectors, possible urban habitats, and recommended environmental management strategies*

<i>Anopheles</i> species	Preferred larval habitat	Environmental management measures for control
<i>An. gambiae</i> s.s.	Temporary small, shallow sunlit pools without vegetation as rain pools, overflow water, roadside ditches, discarded containers, borrow pits, footprints, tire tracks, open drains. Garden wells, irrigation	Water and land management (water level management, flooding, filling, grading, drainage), provision of water supply and sanitation, improvement of rainwater collection, screening, mosquito proofing of houses
<i>An. arabiensis</i> (widespread and abundant in all Afrotropical countries)	Large, deep, cooler permanent bodies of water with emergent vegetation as lakeshore, impoundment, rivers, marshes	Vegetation management, drainage, screening, mosquito proofing of houses
<i>An. funestus</i> (widespread and abundant in all Afrotropical countries)	Coastal brackish water, salt-water marshes and lagoons	Water and land management, screening, mosquito proofing of houses
<i>An. melas</i> (West African coastal swamps, brackish pools Senegal to Angola)	Coastal brackish water, salt-water marshes and lagoons	Water and land management, screening, mosquito proofing of houses
<i>An. merus</i> (East African coastal sandy areas, mangroves and some inland areas where brackish pools form: Somalia to South Africa)	Coastal brackish water, salt-water marshes and lagoons	Water and land management, screening, mosquito proofing of houses

* Sources: Gimnig and others, 2001;⁹² World Health Organization (WHO), 1982;⁹³ Mouchet and Carnevale, 1998;⁹⁴ WHO, 1988.⁹⁵

DISCUSSION

A better understanding of the dynamic process of urbanization, including urban risk factors for health, might lead to the development of suitable health interventions and preventive measures for the rising number of urban inhabitants. We have presented an overview of urbanization trends in Africa and the epidemiology of malaria in these settings. We estimate that about 200 million urban dwellers are currently at risk of malaria. These people are concentrated on a total surface area of less than 500,000 km², representing a maximum of 1.6% of the entire African continent. Consequently, population density in these settings is high, with an average of 400 inhabitants/km². We estimate that 24.8–103.2 million clinical malaria episodes occur annually in urban settings that are endemic for malaria. Since the current estimated global malaria incidence is on the order of 300–500 million cases annually, our estimates indicate that 6–28% of these cases occur in urban African environments. The contribution of malaria to social hardship and heavy economic losses resulting from high health care expenditures and loss of work pro-

ductivity are increasingly acknowledged.⁴ Our review also shows that the epidemiology of malaria in the urban areas is not fully comparable to what is well established for rural settings. For example, urban malaria is characterized by much greater heterogeneity, owing to the dynamic demographic and environmental conditions. Consequently, understanding the spatial and temporal pattern of urban malaria risk will facilitate the design of well-tailored integrated urban malaria control programs.

There is a large body of historical evidence about great achievements of integrated malaria control in urban areas, predating by several decades the advent and large-scale application of DDT. Control measures were largely targeted at the larval stages of malaria vectors by means of source reduction. Application of oil and larvicides on open water bodies often complemented environmental control interventions. For example, Kitwe, an urban mining site in Zambia's copperbelt (estimated population of 12,000 in 1930) benefited from integrated malaria control, commencing in 1931 and sustained for two decades. Extensive water management, (e.g., drainage of swamps, river boundary modifications) and larviciding, together with house screening, use of bed nets and quinine administration to parts of the population were the mainstay of control.^{36–38} The total costs for integrated malaria control measures at Kitwe and three other Zambian copper mining sites over a period of 20 years were US\$ 11 million (expressed in 1995 US\$). The interventions averted an estimated 14,122 deaths and an estimated 517,284 malaria attacks.³⁸

Until World War II, integrated malaria control programs with strong emphasis on environmental management were successfully used in many malaria-endemic areas. Unfortunately, these approaches virtually disappeared during the global malaria eradication campaign in the 1950s and 1960s, which heavily relied on DDT. Environmental concerns, the high costs of repeated application of insecticides, and the development and rapid spread of insecticide resistance have stimulated renewed consideration of environmental management within integrated control operations.³⁹ Urban settings are particularly appealing because of the focal and heterogeneous nature of malaria transmission.^{12,40} Recently devel-

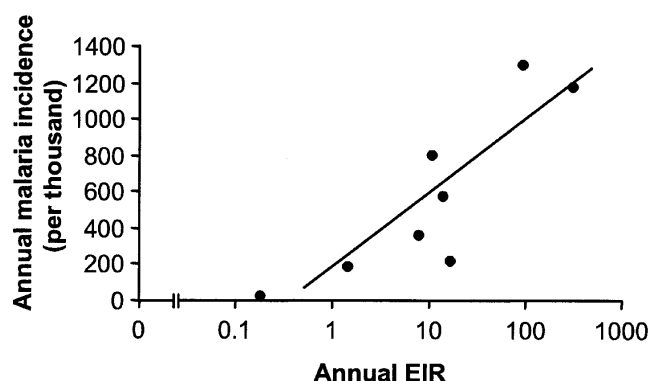


FIGURE 2. Relationship between annual entomologic inoculation rate (EIR) and incidence of malaria among children in African settings. Sources: Vercruysse and others, 1983;⁴⁵ Greenwood and others, 1987;⁴⁶ Velema and others, 1991;⁴⁷ Mbogo and others, 1993;⁴⁸ Delacollette and Barutwanayo, 1993;⁴⁹ Marbiah and others, 1998;⁵⁰ Diallo and others, 2000;⁵¹ and Hay and others, 2000.²¹

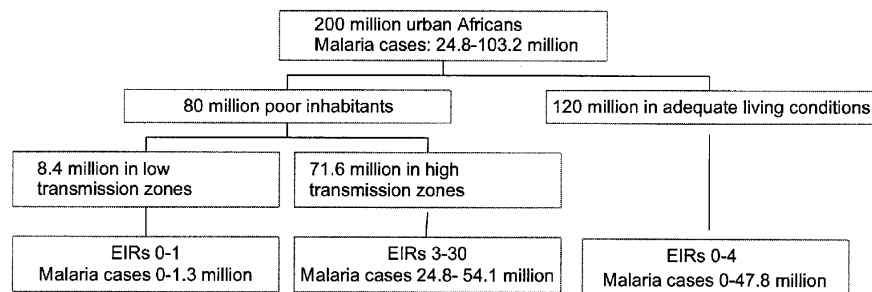


FIGURE 3. Malaria cases in urban African areas endemic for the disease. EIRs = entomologic inoculation rates.

oped malaria transmission models provide further evidence that integrated control approaches, with multiple interventions implemented simultaneously, are crucial for successful malaria control because they suggest drastic reductions in EIRs. They can also reduce malaria transmission by factors of 15–25, which is enough to alleviate mortality.^{41,42}

Currently, malaria control in urban African settings consist mainly of early diagnosis and prompt treatment, and the promotion of ITNs. We propose to strengthen these programs and include environmental management as a key feature for sustainable mitigation of the burden of malaria in urban Africa. Interventions that consider the different facets of the urban environment have the potential to be broadly applicable and affect the health of many inhabitants.⁴³

To provide effective and sustainable malaria control to the urban population of Africa will require massive commitment at national and international levels. Operational constraints such as supply, delivery, or logistics have to be carefully considered to secure long-lasting effective malaria control programs. Private-public partnerships, strategic investments in capacity building, training of national professional and auxiliary staff, health education of the community, and participation are equally important parts of successful integrated control programs. Careful planning in the design and implementation of interventions is paramount since environmental risk factors and malaria transmission depend upon locality. Furthermore, a sound knowledge base of the bionomics of the key malaria vectors and ongoing monitoring of breeding sites and their changes over time is of pressing necessity for the implementation of readily adapted environmental management interventions. Disease risk mapping produced with high spatial resolution imagery can provide an initial basis for identifying and analyzing the determinants of malaria risk, which has been demonstrated in an urban malaria control program in Dar es Salaam between 1988 and 1996.⁴⁴ Pursuing this approach will also ensure that particular attention is paid to highly vulnerable and most disadvantaged urban environments, where the risk of disease-associated morbidity and mortality is highest, and where people are in most need.

In-depth studies are currently underway in the cities of Abidjan (Côte d'Ivoire), Cotonou (Benin), Dar es Salaam (Tanzania), Douala (Cameroon), and Ouagadougou (Burkina Faso) to develop and validate new approaches for rapid appraisal of malaria risk. These studies will facilitate the development and implementation of sound malaria control that will be of relevance for the entire sub-Saharan Africa.

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REFERENCES

1. World Health Organization, 2002. *The World Health Report 2003, Shaping the Future: Reducing Risks, Promoting Healthy Life*. Geneva: World Health Organization.
2. Breman JG, 2001. The ears of the hippopotamus: manifestations, determinants, and estimates of the malaria burden. *Am J Trop Med Hyg* 64 (Suppl): 1–11.
3. Holding PA, Snow RW, 2001. Impact of *Plasmodium falciparum* malaria on performance and learning: review of the evidence. *Am J Trop Med Hyg* 64 (Suppl): 68–75.
4. Sachs J, Malaney P, 2002. The economic and social burden of malaria. *Nature* 415: 680–685.
5. Harpham T, Tanner M, 1995. *Urban Health in Developing Countries: Progress and Prospects*. London: Earthscan Publications.
6. Robert V, Macintyre K, Keating J, Trape JF, Duchemin JB, Warren M, Beier JC, 2003. Malaria transmission in urban sub-Saharan Africa. *Am J Trop Med Hyg* 68: 169–176.
7. United Nations, 2002. *World Urbanization Prospects: the 2001 Revisions*. New York: Population Division Department of Economics and Social Affairs of the United Nations.
8. Knudsen AB, Slooff R, 1992. Vector-borne disease problems in rapid urbanization: new approaches to vector control. *Bull World Health Organ* 70: 1–6.
9. Martens P, Hall L, 2000. Malaria on the move: human population movement and malaria transmission. *Emerg Infect Dis* 6: 103–109.
10. Chinery WA, 1984. Effects of ecological changes on the malaria vectors *Anopheles funestus* and the *Anopheles gambiae* complex of mosquitoes in Accra, Ghana. *J Trop Med Hyg* 87: 75–81.
11. Hutubessy RC, Bendib LM, Evans DB, 2001. Critical issues in the economic evaluation of interventions against communicable diseases. *Acta Trop* 78: 191–206.
12. Carter R, Mendis KN, Roberts D, 2000. Spatial targeting of interventions against malaria. *Bull World Health Organ* 78: 1401–1411.
13. Silimperi D, 1995. Linkages for Urban Health- the Community

- and Agencies. Harpham T, Tanner M, eds. *Urban Health in Developing Countries*. London: Earthscan Publications, 9–33.
14. Phillips DR, 1993. Urbanization and human health. *Parasitology* 106 (Suppl): 93–107.
 15. El Sayed BB, Arnot DE, Mukhtar MM, Baraka OZ, Dafalla AA, Elnaiem DE, Nugud AH, 2000. A study of the urban malaria transmission problem in Khartoum. *Acta Trop* 75: 163–171.
 16. WHO/UNICEF, 2003. *Africa Malaria Report 2003*. Geneva: World Health Organization.
 17. Woyessa A, Gebre-Michael T, Ali A, Kebede D, 2002. Malaria in Addis Ababa and its environs: assessment of magnitude and distribution. *Ethiop J Health Dev* 16: 147–155.
 18. International Energy Agency, 2002. *Energy Statistics and Balances of Non-OECD Countries*. Paris: International Energy Agency.
 19. International Energy Agency, 2002. *Energy Statistics of OECD Countries*. Paris: International Energy Agency.
 20. United Nations, 1999. *Energy Statistics Yearbook*. New York: United Nations.
 21. Hay SI, Rogers DJ, Toomer JF, Snow RW, 2000. Annual *Plasmodium falciparum* entomological inoculation rates (EIR) across Africa: literature survey, Internet access and review. *Trans R Soc Trop Med Hyg* 94: 113–127.
 22. Dietz K, Molineaux L, Thomas A, 1974. A malaria model tested in the African savannah. *Bull World Health Organ* 50: 347–357.
 23. Hagmann R, Charlwood JD, Gil V, Ferreira C, Do Rosario V, Smith TA, 2003. Malaria and its possible control on the island of Principe. *Malar J* 2: 15–23.
 24. Molineaux L, Gramiccia G, 1980. *The Garki Project: Research on the Epidemiology and Control of Malaria in the Sudan Savanna of West Africa*. Geneva: World Health Organization.
 25. Press WH, Flannery BP, Teukolsky SA, Vetterling WT, 1988. *Numerical Recipes in C: the Art of Scientific Computing*. Cambridge, United Kingdom: Cambridge University Press.
 26. Dossou-Yovo J, Doannio JM, Diarrassouba S, Chauvancy G, 1998. The impact of rice fields on malaria transmission in the city of Bouaké, Côte d'Ivoire. *Bull Soc Pathol Exot* 91: 327–333.
 27. Sabatinelli G, Rossi P, Belli A, 1986. Dispersion of *Anopheles gambiae* s.l. in an urban zone of Ouagadougou (Burkina Faso). *Parassitologia* 28: 33–39.
 28. Sabatinelli G, Bosman A, Lamizana L, Rossi P, 1986. Prevalence of malaria in Ouagadougou and the surrounding rural environment during the period of maximal transmission. *Parassitologia* 28: 17–31.
 29. Staedke SG, Nottingham EW, Cox J, Kanya MR, Rosenthal PJ, Dorsey G, 2003. Proximity to mosquito breeding sites as a risk factor for clinical malaria episodes in an urban cohort of Ugandan children. *Am J Trop Med Hyg* 69: 244–246.
 30. Julvez J, Mouchet J, Michault A, Fouta A, Hamidine M, 1997. Eco-epidemiology of malaria in Niamey and in the river valley, the Republic of Niger, 1992–1995. *Bull Soc Pathol Exot* 90: 94–100.
 31. Manga L, Traoré O, Cot M, Mooh E, Carnevale P, 1993. Malaria in the village of Yaoundé (Cameroon). 3. Parasitological study in 2 central districts. *Bull Soc Pathol Exot* 86: 56–61.
 32. Watts TE, Wray JR, Ng'andu NH, Draper CC, 1990. Malaria in an urban and a rural area of Zambia. *Trans R Soc Trop Med Hyg* 84: 196–200.
 33. Snow RW, Omumbo JA, Lowe B, Molyneux CS, Obiero JO, Palmer A, Weber MW, Pinder M, Nahlen B, Obonyo C, Newbold C, Gupta S, Marsh K, 1997. Relation between severe malaria morbidity in children and level of *Plasmodium falciparum* transmission in Africa. *Lancet* 349: 1650–1654.
 34. Snow RW, Craig M, Deichmann U, Marsh K, 1999. Estimating mortality, morbidity and disability due to malaria among Africa's non-pregnant population. *Bull World Health Organ* 77: 624–640.
 35. Coene J, 1993. Malaria in urban and rural Kinshasa: the entomological input. *Med Vet Entomol* 7: 127–137.
 36. Watson MS, 1953. *African Highway: The Battle for Health in Central Africa*. London: John Murray.
 37. Utzinger J, Tozan Y, Singer BH, 2001. Efficacy and cost-effectiveness of environmental management for malaria control. *Trop Med Int Health* 6: 677–687.
 38. Utzinger J, Tozan Y, Doumani F, Singer BH, 2002. The economic payoffs of integrated malaria control in the Zambian copperbelt between 1930 and 1950. *Trop Med Int Health* 7: 657–677.
 39. Ault SK, 1994. Environmental management: a re-emerging vector control strategy. *Am J Trop Med Hyg* 50: 35–49.
 40. Dua VK, Sharma SK, Srivastava A, Sharma VP, 1997. Bioenvironmental control of industrial malaria at Bharat Heavy Electricals Ltd., Hardwar, India: results of a nine-year study (1987–95). *J Am Mosq Control Assoc* 13: 278–285.
 41. Killeen GF, McKenzie FE, Foy BD, Schieffelin C, Billingsley PF, Beier JC, 2000. The potential impact of integrated malaria transmission control on entomologic inoculation rate in highly endemic areas. *Am J Trop Med Hyg* 62: 545–551.
 42. McKenzie FE, Baird JK, Beier JC, Lal AA, Bossert WH, 2002. A biologic basis for integrated malaria control. *Am J Trop Med Hyg* 67: 571–577.
 43. Vlahov D, Galea S, 2003. Urban health: a new discipline. *Lancet* 362: 1091–1092.
 44. Caldas de Castro M, Yamagata Y, Mtasiwa D, Tanner M, Utzinger J, Keiser J, Singer BH, 2004. Integrated urban malaria control: a case study in Dar es Salaam, Tanzania. *Am J Trop Med Hyg* 71 (Suppl 2): 103–117.
 45. Vercruysse J, Jancoes M, Van de Velden L, 1983. Epidemiology of seasonal falciparum malaria in an urban area of Senegal. *Bull World Health Organ* 61: 821–831.
 46. Greenwood BM, Bradley AK, Greenwood AM, Byass P, Jamleh K, Marsh K, Tulloch S, Oldfield FS, Hayes R, 1987. Mortality and morbidity from malaria among children in a rural area of The Gambia, West Africa. *Trans R Soc Trop Med Hyg* 81: 478–486.
 47. Velema JP, Alihonou EM, Chippaux JP, van Boxel Y, Gbedji E, Adegbini R, 1991. Malaria morbidity and mortality in children under three years of age on the coast of Benin, West Africa. *Trans R Soc Trop Med Hyg* 85: 430–435.
 48. Mbogo CN, Snow RW, Kabiru EW, Ouma JH, Githure JI, Marsh K, Beier JC, 1993. Low-level *Plasmodium falciparum* transmission and the incidence of severe malaria infections on the Kenyan coast. *Am J Trop Med Hyg* 49: 245–253.
 49. Delacollette C, Barutwanayo M, 1993. Mortality and morbidity at young ages in a stable hyperendemic malaria region, community Nyanza-Lac, Imbo South, Burundi. *Bull Soc Pathol Exot* 86: 373–379.
 50. Marbiah NT, Petersen E, David K, Magbity E, Lines J, Bradley DJ, 1998. A controlled trial of lambda-cyhalothrin-impregnated bed nets and/or dapsone/pyrimethamine for malaria control in Sierra Leone. *Am J Trop Med Hyg* 58: 1–6.
 51. Diallo S, Konate L, Ndir O, Dieng T, Dieng Y, Bah IB, Faye O, Gaye O, 2000. Malaria in the central health district of Dakar (Senegal). Entomological, parasitological and clinical data. *Santé* 10: 221–229.
 52. Raccurt CP, Arouko H, Djossou F, Macaigne F, Massougbedji A, Zohoun T, Sadeler BC, Ripert C, 1990. *In vivo* amodiaquine sensitivity of *Plasmodium falciparum* in the town of Cotonou and in the vicinity (Benin). *Med Trop (Mars)* 50: 21–26.
 53. Akogbeto M, 2000. Lagoonal and coastal malaria at Cotonou: entomological findings. *Santé* 10: 267–275.
 54. Rossi P, Belli A, Mancini L, Sabatinelli G, 1986. A longitudinal entomologic survey on the transmission of malaria in Ouagadougou (Burkina Faso). *Parassitologia* 28: 1–15.
 55. Carnevale P, Robert V, Le Goff G, Fondjo E, Manga L, Akogbeto M, Chippaux J, Mouchet J, 1993. Données entomologiques sur le paludisme urbain en Afrique tropicale. *Cah Santé* 3: 239–245.
 56. Gazin PP, Goncalves K, Kone B, Lochouart L, 1996. Effects of malaria outbreak in a quarter of the city of Bobo-Dioulasso (Burkina Faso). *Bull Soc Pathol Exot* 89: 200–203.
 57. Lochouart L, Gazin P, 1993. Malaria transmission in the city of Bobo-Dioulasso (Burkina Faso). *Ann Soc Belg Med Trop* 73: 287–290.
 58. Robert V, Gazin P, Ouedraogo I, Carnevale P, 1986. Le paludisme urbain a Bobo-Dioulasso (Burkina Faso). *Cah ORSTOM* 24: 121–128.
 59. Cornet M, Le Hesran JY, Fievet N, Cot M, Personne P, Gounoue R, Beyeme M, Deloron P, 1998. Prevalence of and risk factors

- for anemia in young children in southern Cameroon. *Am J Trop Med Hyg* 58: 606–611.
60. Robert V, Le Goff G, Toto JC, Mulder L, Fondjo E, Manga L, Carnevale P, 1993. Anthropophilic mosquitoes and malaria transmission at Edea, Cameroon. *Trop Med Parasitol* 44: 14–18.
 61. Oduola AM, Moyou-Somo RS, Kyle DE, Martin SK, Gerena L, Milhous WK, 1989. Chloroquine resistant *Plasmodium falciparum* in indigenous residents of Cameroon. *Trans R Soc Trop Med Hyg* 83: 308–310.
 62. Josse R, Merlin M, Combe A, Josseran R, Le Hesran JY, Avenec F, Ngintendem B, Nkongtso AM, Kamwa M, Eboumbou JT, 1988. Comparative study of the malaria indices in Nanga-Eboko, Yaoundé and Edea (Cameroon). *Med Trop (Mars)* 48: 201–208.
 63. Fondjo E, Robert V, Le Goff G, Toto JC, Carnevale P, 1992. Urban malaria in Yaoundé (Cameroon). 2. Entomologic study in 2 suburban districts. *Bull Soc Pathol Exot* 85: 57–63.
 64. Chambon R, Lemardeley P, Boudin C, Ringwald P, Chandenier J, 1997. Surveillance of the *in vivo* sensitivity of *Plasmodium falciparum* to antimalarial agents: the results of initial tests of the OCEAC Malaria Network. *Med Trop (Mars)* 57: 357–360.
 65. Michel R, Carnevale P, Bosseno MF, Molez JF, Brandicourt O, Zoulani A, Michel Y, 1981. *Plasmodium falciparum* and drepanocytic gene in Popular Republic of Congo. I. Prevalence of malaria and drepanocytic trait among school children in Brazzaville area. *Med Trop (Mars)* 41: 403–412.
 66. Trapé JF, 1987. Malaria and urbanization in central Africa: the example of Brazzaville. Part IV. Parasitological and serological surveys in urban and surrounding rural areas. *Trans R Soc Trop Med Hyg* 81 (Suppl 2): 26–33.
 67. Tshikuka JG, Gray-Donald K, Scott M, Olela KN, 1997. Relationship of childhood protein-energy malnutrition and parasite infections in an urban African setting. *Trop Med Int Health* 2: 374–382.
 68. Dossou-Yovo J, Doannio J, Riviere F, Duval J, 1994. Rice cultivation and malaria transmission in Bouaké city (Côte d'Ivoire). *Acta Trop* 57: 91–94.
 69. Ngimbi NP, Beckers A, Wery M, 1982. Survey of the epidemiological status of malaria in Kinshasa (Republic of Zaire) in 1980. *Ann Soc Belg Med Trop* 62: 121–137.
 70. Paluku KM, Breman JG, Moore M, Ngimbi NP, Sexton JD, Roy J, Steketee RW, Weinman JM, Kalisa R, ma-Disu M, 1988. Response of children with *Plasmodium falciparum* to chloroquine and development of a national malaria treatment policy in Zaire. *Trans R Soc Trop Med Hyg* 82: 353–357.
 71. Karch S, Asidi N, Manzambi ZM, Salaun JJ, 1992. The *Anopheles* fauna and the transmission of human malaria in Kinshasa (Zaire). *Bull Soc Pathol Exot* 85: 304–309.
 72. Yohannes M, Petros B, 1996. Urban malaria in Nazareth, Ethiopia: parasitological studies. *Ethiop Med J* 34: 83–91.
 73. Ollomo B, Karch S, Bureau P, Elissa N, Georges AJ, Millet P, 1997. Lack of malaria parasite transmission between apes and humans in Gabon. *Am J Trop Med Hyg* 56: 440–445.
 74. Elissa N, Karch S, Bureau P, Ollomo B, Lawoko M, Yangari P, Ebang B, Georges AJ, 1999. Malaria transmission in a region of savanna-forest mosaic, Haut-Ogooue, Gabon. *J Am Mosq Control Assoc* 15: 15–23.
 75. Lindsay SW, Campbell H, Adiamah JH, Greenwood AM, Bangali JE, Greenwood BM, 1990. Malaria in a peri-urban area of The Gambia. *Ann Trop Med Parasitol* 84: 553–562.
 76. Riley EM, Morris-Jones S, Blackman MJ, Greenwood BM, Holder AA, 1993. A longitudinal study of naturally acquired cellular and humoral immune responses to a merozoite surface protein (MSP1) of *Plasmodium falciparum* in an area of seasonal malaria transmission. *Parasite Immunol* 15: 513–524.
 77. Gardiner CN, Biggar RJ, Collins W, Nkrumah F, 1984. Malaria in urban and rural areas of southern Ghana: a survey of parasitaemia and of anti-malarial practice. *J Trop Pediatr* 30: 296–299.
 78. Afari EA, Akanmori BD, Nakano T, Ofori-Adjei D, 1992. *Plasmodium falciparum*: sensitivity to chloroquine *in vivo* in three ecological zones in Ghana. *Trans R Soc Trop Med Hyg* 86: 231–232.
 79. Bosman A, Modiano D, Voglino MC, Pizzi L, Bartoloni P, Kandia Diallo I, De Giorgi F, 1992. Malaria transmission in a central area of Futa Djallon (Guinea): results of a parasitological survey during the 1989 rainy season. *Parassitologia* 34: 135–142.
 80. Lisse IM, Aaby P, Whittle H, Knudsen K, 1994. A community study of T lymphocyte subsets and malaria parasitaemia. *Trans R Soc Trop Med Hyg* 88: 709–710.
 81. Mendis C, Jacobsen JL, Gamage-Mendis A, Bule E, Dgedge M, Thompson R, Cuamba N, Barreto J, Begtrup K, Sinden RE, Hogh B, 2000. *Anopheles arabiensis* and *An. funestus* are equally important vectors of malaria in Matola coastal suburb of Maputo, southern Mozambique. *Med Vet Entomol* 14: 171–180.
 82. Thompson R, Begtrup K, Cuamba N, Dgedge M, Mendis C, Gamage-Mendis A, Enosse SM, Barreto J, Sinden RE, Hogh B, 1997. The Matola malaria project: a temporal and spatial study of malaria transmission and disease in a suburban area of Maputo, Mozambique. *Am J Trop Med Hyg* 57: 550–559.
 83. Le Bras M, Soubiran G, Baraze A, Meslet B, Combe A, Giap G, Fabre A, 1986. Urban and rural malaria in Niger. The case of the Department of Maradi. *Bull Soc Pathol Exot Filiales* 79: 695–706.
 84. Sowunmi A, Akindele JA, 1993. Presumptive diagnosis of malaria in infants in an endemic area. *Trans R Soc Trop Med Hyg* 87: 422.
 85. Ademowo OG, Falusi AG, Mewoyeka OO, 1995. Prevalence of asymptomatic parasitaemia in an urban and rural community in south western Nigeria. *Cent Afr J Med* 41: 18–21.
 86. Trapé JF, Lefebvre-Zante E, Legros F, Ndiaye G, Bouganali H, Druilhe P, Salem G, 1992. Vector density gradients and the epidemiology of urban malaria in Dakar, Senegal. *Am J Trop Med Hyg* 47: 181–189.
 87. Diallo S, Ndir O, Faye O, Diop BM, Dieng Y, Bah IB, Dieng T, Gaye O, Konate L, 1998. Malaria in the southern sanitary district of Dakar (Senegal). 1. Parasitemia and malarial attacks. *Bull Soc Pathol Exot* 91: 208–213.
 88. Yamagata Y, 1996. *Review of Tanzania-Japan Urban Malaria Control Project (UMCP) in Dar es Salaam and Tanga (1988–1996)*. Final report of a JICA expert on malaria control.
 89. Drakeley C, Schellenberg D, Kihonda J, Sousa CA, Arez AP, Lopes D, Lines J, Mshinda H, Lengeler C, Armstrong Schellenberg J, Tanner M, Alonso P, 2003. An estimation of the entomological inoculation rate for Ifakara: a semi-urban area in a region of intense malaria transmission in Tanzania. *Trop Med Int Health* 8: 767–774.
 90. Gbary AR, Guiguemde TR, Ouedraogo JB, 1988. Emergence of chloroquine-resistant malaria in West Africa: the case of Sokode (Togo). *Trop Med Parasitol* 39: 142–144.
 91. Jambou R, Tombo ML, Raharimalala L, Rakotonjanabelo A, Rabe T, Laventure S, Boisier P, 1998. Malaria in Antananarivo: evaluation of a post-epidemic situation. *Santé* 8: 257–264.
 92. Gimnig JE, Ombok M, Kamau L, Hawley WA, 2001. Characteristics of larval anopheline (Diptera: Culicidae) habitats in western Kenya. *J Med Entomol* 38: 282–288.
 93. World Health Organization, 1982. *Manual on Environmental Management for Mosquito Control*. Geneva: World Health Organization.
 94. Mouchet J, Carnevale P, 1998. Entomological biodiversity of malaria in the world. *Res Rev Parasitol* 58: 189–195.
 95. World Health Organization, 1988. *Urban Vector and Pest Control*. Geneva: World Health Organization.